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Final Report

LIFE SUPPORT PANEL

Volume XI of XI

OAST Space Technology Workshop

LIFE SUPPORT PANEL

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Introduction

The objective of the Environmental Control and Life Support Systems (ECLSS) program is to conduct an orderly Research and Technology development program that will provide matured life support technology for selected future manned flight program objectives. Technology maturity must be achieved via an evolutionary process to ensure that condidate concepts are fully and logically evaluated, and then adequately developed prior to selection of the final concept for any space opportunity being directed toward a specific mission application.

As previously noted, the cost of providing expendable items for the life support function becomes prohibitively expensive as mission duration increases; therefore, regenerable techniques must be employed. The program proposed here provides for the research and development of regenerative-class life support breadboard systems for laboratory testing, and the development and checkout of integrated flight hardware. This study uses, as convenient focal points, successively ambitious future manned spaceflight opportunities as shown in Figure 1. The life support technology required for these opportunities shows increasing degrees of system closure as the NASA manned space program progresses in the future (see Figure 2).

The Life Support program, outlined in this study may be divided into two program categories: (1) A sustaining R&D program that is needed to provide the basic and applied research to supply new ideas, approaches and concepts, and necessary development of these to show feasibility and optimum application potential; and (2) the specific Life Support Projects responsible for the further development, testing and integration into flight certified

prototype hardware. This latter work is necessary to establish, both in ground tests and flight tests, the correctness and suitability of the system. Each succeeding manned spaceflight opportunity depends on previous accomplishments, both technical and programmatic. As an example, the final testing of a Mars Lander ECLSS is seen as being accomplished in near-Earth orbit, and dependent upon an orbiting Space Base. Similarly, the first of the biological systems, expected to be required for a permanent Lunar Habitat would first be set up and demonstrated, in a reduced scale, within a temporary Lunar Colony.

Work in other related areas of life sciences needs to be successfully accomplished in addition to the life support and protective systems for these future missions. This includes other disciplines within the Office of Life Sciences, such as medical, physical, psychological considerations and requirements, man-machine relationships, and social group dynamics. Advanced space suits and protective systems will play an important part in the success of these future missions. Advanced EVA capability will be required in order to provide for contingencies and to enhance man's capability for deploying and servicing payloads, erecting large structures, and to minimize space payload costs.

This report has been prepared by NASA personnel whose expertise is mainly in the area of life support concept and hardware development. Therefore, this report concentrates on life support and crew equipment facets and not on behavioral sciences and other facets of man's relationship to the space environment. There are, however, ongoing activities in these areas as a portion of the overall NASA Life Sciences Program. In fact, studies are being performed to define specific Spacelab experiments to be flown as

dedicated Life Sciences payloads in accordance with "the 1973 NASA Payload Model".

The methodology used in arriving at the results of this workshop study is shown in Figure 3. Additional factors and limitations to the study complied by the OAST Workshop Life Support Group are:

1. Life Support functions and supplies obtained from manufacturing processes or from extraterrestrial raw materials have not been considered.
2. Transportation costs necessary to use life support equipment in space either as an experiment or for producing a habitable environment on-board a spacecraft have been excluded from resource forecasts.
3. Pollution control for extraterrestrial colonies and habitats has not been considered as a life support system function
4. No unforseen breakthroughs in life support technology have been considered to occur during the time period considered in the technology forecast.
5. Resource forecasts have been made on the basis of 1975 dollars.

For purposes of this report life support technology has been subdivided into two main classes: (1) Physico-Chemical ECLSS Systems; and (2) Biological Life Support Systems. The various systems are described in the next section of the report.

Another section discusses a forecast for technical advancements in terms of projected manned space flight opportunities, including anticipated flight experiments.

Summary

Life support technology advancements in terms of system closure and regeneration capability were analyzed for a variety of manned space opprotunities. It has been determined that regeneration capabilities must be developed in a step-wise fashion through space flight experiments and continued SRT supported R&D to meet the succession of increasingly ambitious space opportunities. In particular, SRT supported development of biological type life support systems must be implemented for the realization of long term space goals.

Regeneration and system closure have been shown to be dependent on mission duration, spacecraft crew size, cost of resupply and spacecraft power source. The evolution of life support technology must include water recovery, oxygen recovery, waste management recycle and, ultimately, a man-made closed ecology with selected biological species before large-scale permanent space habitation can become possible. A NASA Life Sciences dedicated regenerative ECLSS experiment has been identified in the workshop study as a necessary precursor to the flight certification of regenerative capabilities necessary for a Space Station. Other possible life support experiments that are needed for other space opportunities have been identified as.

- Water recovery (vapor compression distillation)
- Water electrolysis (solid polymer electrolyte)
- Nitrogen generator
- Crew appliances
- Solid waste management
- Microbiological/plant/animal experiments

Basic research needs were identified to be:

- Identify purity standards, methodology and measurement techniques for establishing "safe" water
- Identify manned spacecraft air quality standards
- Identify effects spacecraft contamination on optical sensing devices
- Identify cleanliness stardards for long duration space mission crewmen

LIFE SUPPORT AND PROTECTIVE SYSTEMS

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LIFE SUPPORT AND PROTECTIVE SYSTEMS

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I. FORWARD

Life support and protective systems, as a technology discipline within NASA, encompasses (1) the control and revitalization of a habitable atmosphere; (2) food and water provision; (3) solid and liquid waste management; (4) space suits and emergency equipment for personnel safety and rescue; (5) personal hygiene and crew appliance facilities; and (6) special instrumentation and data management equipment.

The Environmental Control Life Support Systems (ECLSS) used in spacecraft have been relatively simple storage and expendable systems to maintain life. They have been characterized in the Hearth Committee OFS Study as "stow and throw systems". Use of stored and expendable items without any regeneration has been possible, in most instances, because of the short duration missions flown in the manned space program. Skylab Missions, however, lasted up to a total of 172 days; and because of the longer duration missions, the Skylab used in a regenerable molecular sieve system to control metabolically generated carbon dioxide. The Space Shuttle and the Spacelab are short term missions and will utilize expendable life support system technology.

Regenerable life support life systems, such as the molecular sieve, are very important to future forecasted manned space opportunities (beyond the Shuttle Era) that are characterized by mission durations from a few months to a number of years and travel to the far reaches of the geosphere. The use of expendables rather than regenerable systems in these missions will become prohibitively expensive in terms of logistic costs; and even though regenerable systems may be bulkier, weigh more, and consume more power than

short term expendable systems, the costs of utilizing expendable systems eventually will exceed those of regenerable systems (see Figure 4.)

The systematic development of regenerable technology is required to provide closure of life support systems and to eliminate expendables for: carbon dioxide removal; oxygen regeneration; contaminant control; water recycling and reclamation; solid waste collection, transport, and treatment; trash handling and treatment; personal hygiene; clothes washing; EVA portable life support systems; and food technology.

The ultimate life support system must take the form of those on spaceship-earth--a closed-cycle biological life support and provision system, wherein plants will recycle carbon dioxide to carbonacious foodstuffs and oxygen; selected animal species will produce protein and lipids; water reclamation and waste management will be completed by microorganisms and other simple life forms, and man will live in symbiotic relationship with other living things as he does on earth. It is conceivable but not proven that such a man-made closed ecology system, enormously complex as it must be, is capable of sustaining human life for an indefinite time. Closed ecology, including a diversity of life forms (microbiological, plant, and animal), is addressed by the OFS study as a technical objective of space exploration that contributes to national needs and goals. By developing and acquiring the knowledge of how to construct a biological ecosystem capable of supporting man independent of earth supplies and resources, we will be able to establish a basis of how man must interact with earth in order to preserve and possibly improve our environment and ecosystem. This is considered to be an extremely important body of knowledge and should add impetus in conducting this life support research.

This section of the OAST Space Technology Workshop Report reviews the recommendations from the Outlook for Space and the prospective on NASA future space program planning. A summary of both the technology requirements for physico-chemical and biological life support systems, and the flight experiment and project development requirements is also made.

II. LIFE SUPPORT SYSTEMS DESCRIPTION

A. Physico-Chemical Life Support Systems

All life support systems technology in use today, or being actively investigated for future application falls within the Physico-chemical process category. This includes chemical absorption (e.g., CO_2 absorption by lithium hydroxide), chemical adsorption (e.g., trace contaminant removal by charcoal), electrochemical processes such as electrochemical CO_2 removal and concentration, chemical processes such as CO_2 reduction in Sabatier reactors, water purification by a number of processes such as distillation, ultrafiltration, reverse osmosis, ion exchange, etc. Physico-chemical process hardware requires active process controls such as temperature, flow rate, etc., and are subject to wear, corrosion, being consumed (used up), and thus, have a finite useful life. The hardware is amendable to routine maintenance, and unscheduled repair or replacement, provided spares are made available. Certain elements of these systems such as; valves, fans, pumps, etc., will have to be utilized in any life support system, including the biological systems discussed in the following section, and are being given special attention in so far as reliability, commonality, repair and/or replacement is concerned.

It is anticipated that these Physico-chemical processes will serve most future life support needs with the exceptions of permanent Space Bases, Lunar Habitats, and other mission opportunities that have (1) high resupply costs associated with their location, (2) are required to support large numbers of occupants, and (3) have a useful life that is greater than a few years.

Physico-chemical processes can also be utilized to produce nutrients such as glycerol and ethyl alcohol that can be used as dietary supplements.

The outlook for space forecast has pointed out that synthesized chemicals could be utilized to supply approximately 30% of a space crew's diet. Chemical techniques for synthesizing materials such as glycerol have been demonstrated; but the processes require considerable development before they are suitable for space use.

As indicated previously, extra-vehicular activity (EVA) will be required for all foreseeable manned space missions to provide for contingencies and to enhance man's capability for deploying and servicing payloads, erecting large structures, and to minimize space payload costs. Current EVA capability is represented by the Apollo A-7 suit, used in conjunction with a portable life support system (PLSS) or umbilical life support system. This suit is operated at 3.7 psia and has seen service on both the lunar surface and (with modifications) aboard Skylab.

B. Biological Life Support Systems

Biological life support systems are considered to be those microbiological, plant, and animal systems which provide life support functions and/or food production. Previous NASA sponsored, R&D activity has been limited to investigations with unicellular systems (algae, hydrogenemonas eutropha, etc.) and intensive agriculture units for selected vegetables. A closed ecological system is envisioned as a "farm" concept including numerous physico-chemical processes. For example, a solid waste treatment system (incineration) may be required to control fecal bacteria, and chemical synthesis of nutrient supplements may be desirable or needed.

III. TECHNOLOGY FORECASTS AND PROJECT OPPORTUNITIES

Figure 5 shows forecasted life support technology in terms of relative resource requirements for the manned spaceflight opportunities illustrated in Figure 3. Both SRT (supporting research and technology) and project resources are indicated. The SRT resources, which provide for various development programs, (to demonstrate feasibility, indicate application potential and improve performance of new or existing concepts and designs) is divided into physico-chemical and biological systems. Forecasted project resources are keyed to the opportunities in Figure 3 by the numerical designators in the project resource areas.

The various resource areas indicate relative levels of effort for (1) research and development, and (2) flight certification necessary to provide reliable life support systems for each of the identified space opportunities from Figure 3. Resources are chiefly influenced by the complexity, size, degree of regeneration (closure) and reliability of the required life support system. Each successive space opportunity presents a unique combination of the influencing factors and represents a discrete set of requirements to impact life support system design. Therefore, although actual resources may differ from the forecast, the ratio of the attendant resources between each of the eight representative life support systems should not change significantly.

A gradual rise in biological system development resources is expected and reflects the difficulty of the problem: the anticipated increase in the numbers and complexity of animal/plant species; the complexity of animal/plant

micro-organism interactions; nad the associated experimentation. Physico-chemical system development, unlike biological development, has been taking place for a number of years, resulting in relatively well understood technologies for ECLSS having oxygen and water closure. Significant increases in physico-chemical SRT resources are not expected.

The L-5 habitat experiment will require the largest amount of project resources because of its inherent complexity.

A. Development Activities

Physico-Chemical Life Support Systems

Figure 5 shows a relatively consistent level of effort projected into the future for Supporting Research and Technology for physico-chemical life support systems. This effort provides a sustaining technology development program to support new concept initiation, development and testing, improvement of existing or established concepts and subsystem and sytem-level tests to verify performance and operation. The technology development that is envisioned to meet the goals of future space opportunities is dependent upon the sustaining SRT programs to provide the technology base and to develop reliable life support processes derived from the technology base. Specific endeavors (currently underway) in this program are atmosphere revitalization and control processes, water-waste management processes, subsystem instrumentation, control, and interface requirements, food provisions and food service equipment (including basic research into chemical food synthesis processes), and system integration studies and tests.

Development activity is underway for a 4.0 psia suit to support Shuttle EVA. This suit, designated as an extravehicular mobility unit (EMU), will

provide improvements in suit performance and useful life and is expected to cost somewhat less than the Apollo suit. Technology improvements to be incorporated into the EMU are: integrated suit-backpack configuration, self-donning and doffing, improved arm and glove mobility, longer shelf and service life, less expensive manufacturing processes, modular sizing and replacement capability, and simple servicing needs.

Advances is space suit design and associated portable life support systems (PLSS) for future use will involve incorporation of higher suit pressure capability, up to 8 psia. This is important because future spacecraft (including Shuttle) are expected to use 14.7 psia atmospheres, and the transition from the cabin (14.7 psia) to EVA suits (8 psia) can be accomplished without prebreathing. (Prebreathing for 2 1/2-3) hours is necessary when transitioning from 14.7 to 4 psia in order to avoid nitrogen bubble formation within the body.) Other expected advances are: faster suit donning and checkout for quick-response EVA capability; greater whole-suit mobility; reduced bearing leakage; reduced expendable inventories through use of regenerable CO_2 scrubbing and thermal sinks; and increased radiation/ meteorite protection for geosynchronous and deep space EVA.

Ultimately, a 14.7 psia, two-gas (oxygen and nitrogen) atmosphere suit and life support assembly may be both necessary and beneficial. A two-gas atmosphere will be needed to eliminate frequent (perhaps daily) exposure to 8 psia pure oxygen for periods up to 8 hours, which may present a toxic hazard.

Biological Life Support Systems

Previous "closed" life support studies and development activities have

concentrated on either chemical food synthesis or unicellular biological systems. The life sciences community in NASA is currently planning for various plant and animal experiments to be flown on Spacelab. The flight duration is very short in comparison to plant and animal life cycles and the information of the effects of zero-g will be limited. Very little ground-based biological life support system work is being conducted at this time. It has been pointed out previously that the ultimate development of a closed ecological life support system, involving a significant number of biological species, will require substantial resource commitments on the part of NASA. In order to be successful, this program will also require 50-75 years of planned and orderly research and development.

Initially, a knowledgeable team of experts in related technology areas (biochemistry, ecology, plant physiology, animal husbandry, nutrition, organic chemistry, microbiology, etc.) must be organized as a team to review closed life support system requirements and to model such a system. NASA does not currently possess such expertise. This effort and follow on iterations would require approximately two years and would result in recommendations for future R&D. The R&D would be initiated with individual plant and animal investigations; and, as individual systems are developed, increasingly complex integration studies and tests must be performed. The ground-based SRT efforts must be closely coordinated and must also be coordinated with flight experiment findings to insure ultimate success.

B. Project Opportunities

The next section of this report will outline the major anticipated space activities that NASA will undertake in future years. Each of these activities,

such as Space Stations, Lunar Colonies, and Manned Mars Missions is discussed in terms of the anticipated life support requirements. Also discussed are the relationships that exist between experiment opportunities occurring with each of the space activities, and how these experiments provide a technology base for improvements in life support systems on subsequent missions.

Regenerative Environmental Control Life Support System Experiment

A significant amount of research and development has been conducted by NASA on regenerative life support processes, and some intermediate-duration earth-based system and subsystem tests have been performed. However, usage and acceptance of regenerative techniques and advanced life support processes in the manned space program depend upon the certification of a reliable cost-effective regenerative ECLLS. The effects of weightlessness on the performance of an ECLSS and the associated man-machine relationships cannot be adequately defined with earth-based tests or aircraft zero-g simulation. A space flight experiment is required. A 30-day Life Sciences dedicated payload, planned for a 1983 launch, has been identified as an early Shuttle candidate payload and offers the only logical opportunity for a timely ECLSS flight test. In order that the regenerative ECLSS experiment can be developed for a 1983 launch date with a minimum expenditure of funds, a development program has already been initiated. The program will be conducted in two phases.

Phase I--Preprototype development (1975-1979) will contain the following tasks:

1. Define the ECLSS and Spacelab/experiment interfaces and

prepare a tentative preliminary design.

2. Design and fabricate independent ELCSS subsystems towards meeting Spacelab interfaces.

3. Perform ground-based testing with integrated groupings of ECLSS subsystems.

Phase II--Prototype development and flight hardware (1979-1982) will contain the following tasks:

1. Design and fabricate an ECLSS to fit Spacelab.

2. Evaluate the integrated ECLSS both with unmanned and manned tests.

3. Construct and install a set of flight hardware (duplicate) or prototype.

The ECLSS experiment will provide life support for Spacelab payload crew (2 to 3 men). The vehicle ECLSS will back up the ECLSS experiment as required. Crew support for the ECLSS experiment will be planned on a noninterference basis to integrate with other Life Sciences experiments in accordance with protocol adopted for the mission. A schematic diagram of the proposed regenerative ECLSS experiment is shown in Figure 6.

The ECLSS experiment will use proven regenerative technology advancements from ongoing developments within the NASA Life Sciences program. The functional elements of the ECLSS experiment are:

1. CO_2 Removal--Electrochemical concentrator to remove carbon dioxide from cabin air.

2. CO_2 Reduction--Sabatier reactor to reduce CO_2 with H_2 to form water.

3. Oxygen Generation--Solid polymer electrolysis unit to produce

hydrogen and oxygen from water.

4. Pressure Control--Oxygen and diluent (nitrogen) adjustment to maintain a viable cabin atmosphere.
5. Contaminant Removal--Catalytic oxidation and chemical absorption to convert cabin air contaminants primarily to water vapor and carbon dioxide.
6. Urine Processor--Vapor compression distillation and electrochemical iodination to treat urine and recover, sterilize, and store potable water.

In addition to this baseline ECLSS experiment, other internal self-contained experiments will be attempted in the same payload if there is adequate space and power. The proposed self-contained experiments are:

1. Air Revitalization--Unitized control of water vapor (humidity) and CO_2 to supply oxygen.
2. Wash Water Reclamation--Hyperfiltration through membranes to recover potable water from waste wash water.

Other features of the experiment include:

1. A maintenance demonstration to examine the problem of performing in-flight component removal and replacement.
2. The use of common components to the greatest extent possible to reduce development costs and demonstrate commonality, particularly, common instrumentation.
3. The use of automatic fault detection and isolation techniques to assist maintenance/repair tasks and system operation monitoring.

These features will probably be demonstrated on selected subsystems to save costs rather than on the complete ECLSS. Thus, these features must be expanded

and upgraded in order that the ECLSS for a space station will perform in an optimum manner. In addition, the ECLSS experiment will provide flight certified water and oxygen recycle technologies, and trace contaminant control technology needed for space stations and other space opportunities which will require physico-chemical ECLSS.

This regenerative ECLSS experiment will produce information of performance and control dynamics, including materials balances and liquid/gas separation. Also, man-machine interfaces and relationships will be evaluated. Most importantly, information will be obtained to verify integration design, including unit-to-unit and system-to-vehicle interfaces. Future application of regenerative-class ECLSS will rely heavily upon this information. No biological life support technology is planned for this experiment.

Experiments: Autonomous Spacelab experiments to evaluate the vapor compression distillation and solid polymer electrolysis units are being developed through the preprototype stage. The performance of these units is more sensitive to a weightless environment than other ECLSS components and units; therefore, a precursor Spacelab flight experiment may be warranted.

Small Space Station

A small Space Station is foreseen as a forerunner to a larger Space Station and future space opportunities. A crew of 3 to 6 men is proposed for the station which will probably be flown in a low earth orbit and resupplied periodically by the Shuttle. The life support system of the small Space Station will be similar to and will depend on the technology demonstrated in the Regenerative ECLSS experiment. Closure of the oxygen loop (as

demonstrated in the flight experiment), however, will depend upon the power source used and power demands of the Space Station. (Regeneration of oxygen is feasible when power sources other than hydrogen-oxygen fuel cells are used, but over 700 watt-hours per man-day are necessary in the oxygen regeneration process.)

Regenerative CO_2 removal and water reclamation subsystems will be incorporated into this ECLSS, as baseline subsystems. It is expected that much of the necessary design and integration activities and the development of specialized life support instrumentation and information management items for this ECLSS will be derived from the regenerative environmental control life support system experiment (RECLSSE). Furthermore, on-line maintenance requirements, common components, and spares inventories must be incorporated into the Space Station and its resupply cycle.

Experiments: The small station will provide the opportunity to conduct a variety of experiments leading to improved life support functions and additional system closure. Based on the technology demonstration accomplished with the RECLSSE, oxygen reclamation experiments may be conducted, leading to the establishment of this technology as a baseline system for the large Space Station.

Large Space Station

It is expected that at least twelve persons will occupy the large Space Station, and that the resupply period will be increased relative to that of the small Space Station.

These mission objectives dictate an ECLSS with a greater capacity, larger spares inventory, improved fault detection systems, and greater system

closure than previously flown. The life support processes that are envisioned for the large Space Station will probably include the closure of the oxygen cycle, which, with the reclamation of water from liquid wastes, will materially reduce the need for resupply of expendables. Technology for upgrading the ECLSS in this matter will be obtained from flight certification experiments conducted on the small Space Station and Spacelab.

Since the large Space Station will probably be used to study and evaluate the assembly of large structures in space, extended EVA capability will be necessary. An EMU with regenerative capabilities should be used to reduce expendable provisions such as Lithium Hydroxide for CO_2 removal.

Experiments: The large Space Station will also provide an opportunity to extend waste management technology by testing waste management-reclamation techniques such as the waste incineration or wet oxidation units. These experiments will reduce storage volume needed for wastes, and will also provide additional water and oxygen for life support system closure. In addition, nitrogen generation experiments will be conducted to provide a source of this diluent gas from liquid storage (ammonia or hydrazine). Small biological experiments, and plant growth studies will also be conducted, and may provide some modest vegetable additions to the food supply.

Space Base

Utilization of space for purposes of product manufacture, earth-beamed power generation and other practical applications will be made possible with the Space Base. Various specialists and a cadre of workers will inhabit Space Base which may be assembled in a geosynchronous orbit with materials ferried

from earth. Also, raw materials and manufactured products will be frequently shuttled between earth and the Space Base.

Because of the frequent Shuttle flights, a large store of life support system spare components may not be necessary. Instead, spares may be supplied from earth as needed to replace failed components in redundant type ECLSS modules that will operate at increased capacity to compensate for failed systems. A major advance in the Space Base ECLSS is closure of the water/waste management system. Closure of this system reduces the amount of stored waste, which ultimately must be removed from the Space Base, and increases availability of water supplies and other usable commodities, e.g., carbon dioxide.

The EVA requirements for Space Base will be greatest during original erection and assembly of the base. If solar power generation, or other large structures are to be constructed using the Space Base as an operational platform for these activities, EVA will again be necessary.

Experiments: Experiments in support of future life support capability will be conducted on board the Space Base. Both biological and physico-chemical food production will be investigated. In addition, the Mars Lander ECLSS may be tested under realistic conditions to insure reliable, unsupported life support functions before commitment to the Mars Flight.

Lunar Colony

The establishment of a 6-12 man Lunar Colony will provide the basis for the eventual establishment of a permanent Lunar Habitat. Occupancy by a crew of 6-12 people, with crew exchange and resupply occurring periodically with a lunar lander, will allow a useful colony life of several years.

It is expected that closure of the oxygen cycle and water cycles will be incorporated into the life support system, however complete waste management recycling may not be cost effective. Maintainability and spares inventory management should be emphasized in this ECLSS because of the increased logistic cost of the Lunar Colony compared with earth orbit logistic costs.

Experiments: An excellent opportunity exists within the Lunar Colony for the performance of biological experiments. Planning for this goal is required, so that either filtered sunlight, or artificial light is available. Experiments to determine the suitability of lunar soil for plants should be conducted in preparation for extensive biological food growth and biological life support system experiments in a subsequent Lunar Habitat.

In addition, experiments to determine the extent to which useful commodities for life support can be derived from available lunar materials will be of considerable interest, and may well affect the requirements for life support systems used on the moon.

Lunar Habitat

At some point, subsequent to the establishment and use of a Lunar Colony, a permanent Lunar Habitat will be established. Personnel compliment of such a habitat is difficult to predict; however, eventually as many as 200-300 occupants would seem reasonable. Other assumptions which impact life support system configurations, and particularly the degree of system closure, is the relative cost of power (primarily electrical) in terms of \$/kw.hr on the lunar surface, vs. \$/kg of supplies delivered to the lunar surface.

With these drivers in mind, a closed life support system with the exception of food generation is expected to be optimal for the Lunar Habitat considering the logistic cost of oxygen and water resupply. System closure will include waste management recycling to reduce waste disposal and further reduce logistic requirements.

Experiments: The Lunar Habitat will provide an ideal setting for the development of both physico-chemical and biological food production. The 1/6 gravity of the moon will aid in these efforts, especially in the problems of liquid-gas phase separation. The resulting technology developments will not be directly applicable to other future space programs unless similar g levels are used. However, the eventual closure of the food cycle will depend heavily on the knowledge gained in the Lunar Habitat, and this capability, as it is developed, will reduce, and perhaps eventually eliminate logistic resupply of food to the Lunar Habitat.

Manned Mars Lander

Manned missions to the planet Mars, including both flyby and/or landing, present unique problems for the life support system. Such a system must have attributes which tend to be mutually exclusive: a light-weight, low power system that minimizes expendables (i.e., regenerative in function) and exhibits very high reliability for a relatively long duration mission (300-500 days).

The need for light-weight, low power life support systems needs no explanation. Minimization of expendables to achieve low weight dictates regenerable systems which, by their very nature, are more complex than

expendable systems (e.g., water reclamation vs. stored water). The achievement of very high reliability is essential on a Mars mission because no mission abort or rescue can be performed once the spacecraft is in an orbit to Mars. A key to the solution of this problem is maintainability, but this alone will not provide easy solutions. Extensive development and test programs must be carried out to insure not only mission success, but to preserve and protect the lives of the crew.

It is strongly recommended that a manned Mars spacecraft, with all onboard systems functional, be manned in earth orbit, perhaps in the immediate vicinity of the Space Base, or other manned orbital spacecraft, for at least an equal time period, prior to embarking on an actual Mars Mission.

Life support system concepts that will fit the needs of a Mars mission are closed physico-chemical processes for atmosphere revitalization and water-waste management. Stored, freeze-dehydrated food, reconstituted with reclaimed water will provide minimum food weight penalties (about 0.5 pound per man-day). Since oxygen reclamation will probably prove to be superior to stored oxygen systems (about 2 pounds per man-day) considerable electrical power will be needed to produce oxygen from metabolically produced carbon dioxide and water (several hundred watt-hours per man-day).

No life support-oriented experiments are expected to be conducted onboard this mission.

L-5 Prototype Experiment

This biological system flight demonstration is planned as an experiment to be performed on the Space Base which would have a primary physico-chemical life support system closed for atmosphere revitalization and water.

This biological system may not be a completely balanced system or support significant manpower complement, but it should ultimately contain all significant biological species necessary to demonstrate balanced system operation and address all the critical interface problems (microbiological/plant/animal/physico-chemical) that are pertinent to a closed ecological system for an L-5 colony (e.e., water balance, oxygen balance, waste recycling--animal and plant waste conversion to plant nutrients, etc.). The primary physico-chemical life support system or its individual subsystems will be utilized in a back-up mode or in a complementary mode with the biological system, and provide the primary life support capability that will insure habitability of the Base and allow for conducting the biological system tests.

The complexity of an L-5 experiment remains to be defined, just as the complexity of a space colony must be defined (a Stanford/Ames/ASEE summer workshop is currently conceptualizing a design for an L-5 colony).

IV. TECHNOLOGY REFERENCES

LIFE SUPPORT TECHNOLOGY

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LS-3	Internal NASA Review Draft Report of the Outlook for Space Study, National Aeronautics and Space Administration- July 1975
LS-4	Internal NASA Review Draft Outlook for Space, Executive Summary, National Aeronautics and Space Administration, July 1975
LS-5	The 1973 Payload Model Space Opportunities 1973-1991, June 1973
LS-6	Final Report, Space Shuttle Payload Planning Working Group--Life Sciences, May 1973
LS-7	Annual Reports The Development and Testing of an Intensive Agricultural System for Space Application. Western Regional Research Laboratory, U.S. Department of Agriculture, Agricultural Research Service, Berkley, California 94710, NASA Contract No. A474-29A, March 1971--March 1972--March 1973
LS-8	NASA SP-134, The Closed Life-Support System, National Aeronautics and Space Administration, Ames Research Center, Moffett Field, California, April 14-15, 1966
LS-9	Moonlab, A Study By Stanford-Ames Summer Faculty Workshop in Engineering Systems Design, June 29-Sept. 6, 1968

LS-10 NASA Project Approval Document Research and Development Integrated Life Sciences, ILS 1975, April 23, 1975

LS-11 Alternate Mission Studies, (AILSS), Hamilton Stardard Division of United Aircraft Corporation, Windsor Locks, Connecticut, July 1969, NASA CR-66876

LS-12 Final Report, Study of Space Shuttle Environmental Control and Life Support Problems, by K.P. Dibble, F.E. Riley, et al, prepared under Contract No. NAS1-10478 by Lockheed Missiles & Space Company, Sunnyvale, California, for NASA Langley Research Center, NASA CR-111978, November 11, 1971

LS-13 Final Report, Space Shuttle Environmental Control/Life Support Systems, Hamilton Standard Division of United Aircraft Corporation, Windsor Locks, Connecticut, Contract No. NAS1-10359, September 2, 1971

LS-14 Trade-off Study and Conceptual Designs of Regenerative Advanced Integrated Life Support Systems (AILSS), United Aircraft Corporation, Windsor Locks, Connecticut, for Langley Research Center, NASA CR-1485, January 1970

LS-15 Preliminary Edition of Reference Earth Orbital Research and Applications Investigations, (Blue Book), Volume VIII--Life Sciences, NASA, NHB 7150.1, January 15, 1971

LS-16 Environmental Control and Life Support Systems Development for Manned Spacecraft 1960-1973, D.C. Popma, Manager, Integrated Life Support Systems, NASA Headquarters, Washington, D.C. 20546, Life Support Systems and Equipment Session at the XXIV International Astronautical Congress held at Baku, USSR in October 1973

LS-17 Final Report, Definition Study for an Extended Manned Test of a Regenerative Life Support System, November 1971, prepared under

Contract No. NAS1-10790, by the Biotechnology and Power Department, Advanced Systems and Technology, McDonnel Douglas Astronautics Company, Huntington Beach, California Langley Research Center, NASA CR-112000, MDC G-2624.

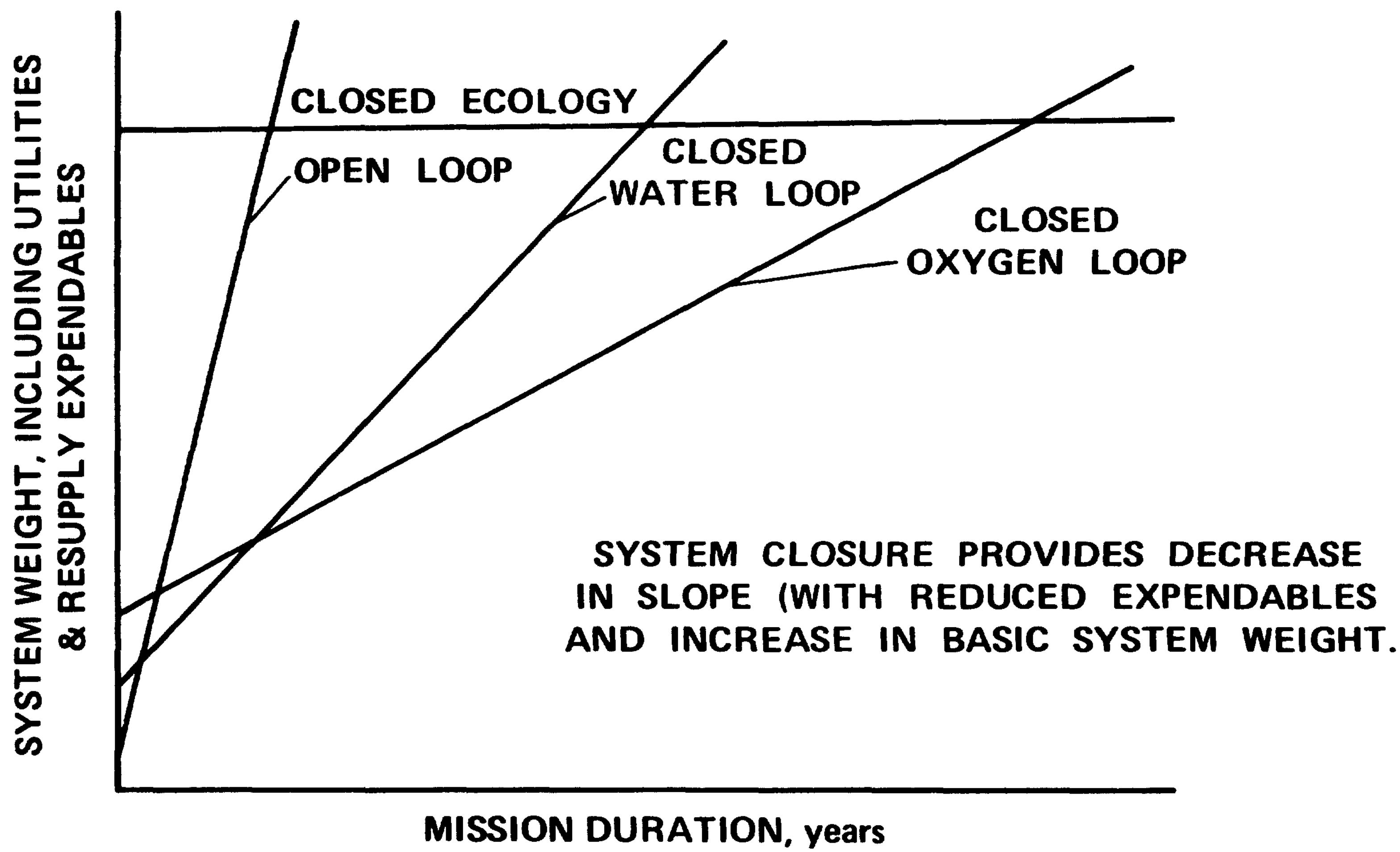
LS-18 Preliminary Test Plan, Definition Study of an Extended Manned Test of a Regenerative Life Support System, November 1971, prepared under Contract No. NAS1-10790, NASA CR-111999, MDC G-2625

LS-19 Test Report, Test Results, Operational Ninety-Day Manned Test of a Regenerative Life Support System, May 1971, prepared under Contract No. NAS1-8997, NASA CR-111888, MDC G-2282

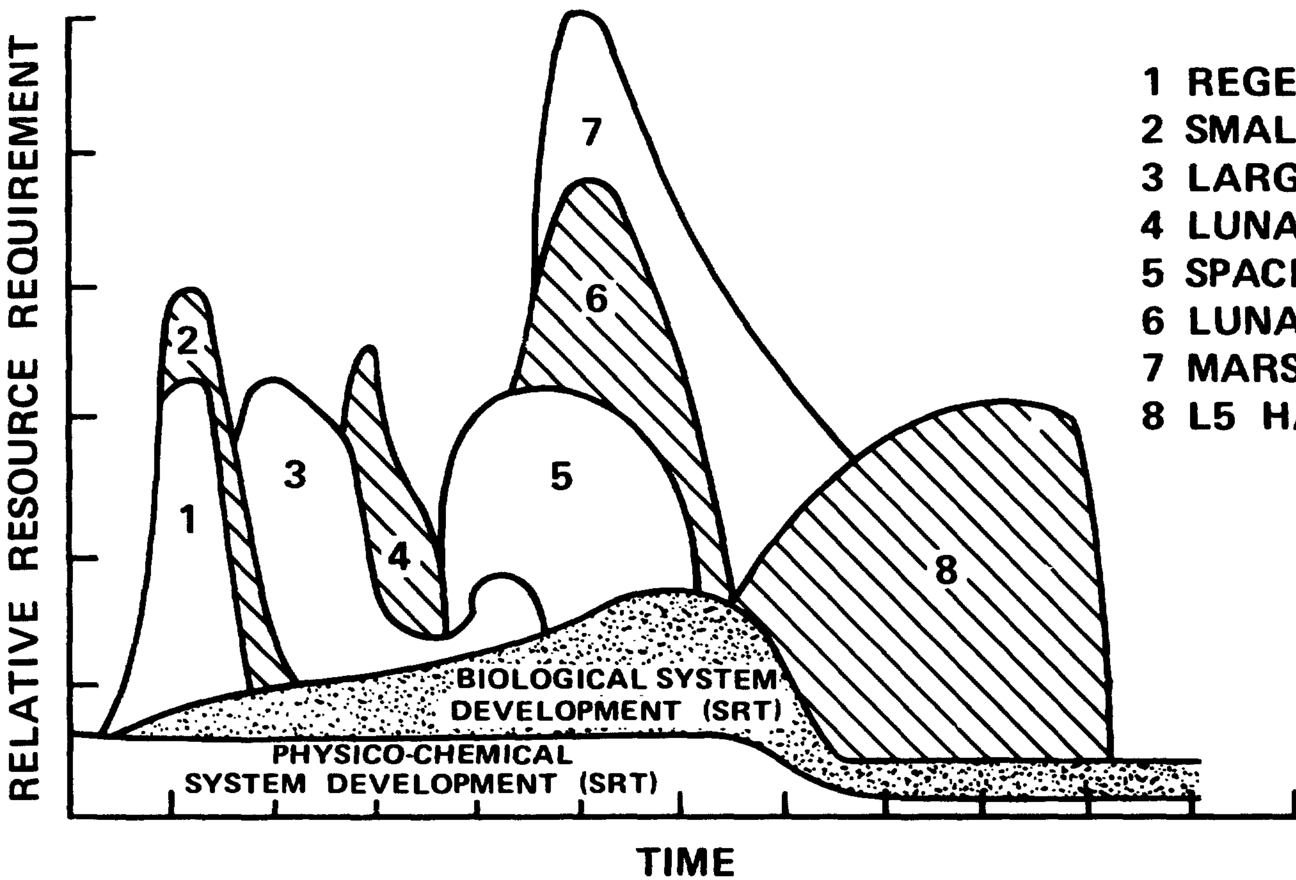
LS-20 Preliminary Results from an Operational 90-Day Manned Test of a Regenerative Life Support System, A Symposium held at Langley Research Center, November 17-18, 1970, NASA SP-261

LS-21 Study to Evaluate the Effect of Extra Vehicular Activity on Payload Systems, NAS2-8429, Mid-term report, November 25, 1974, SA-0172

LIFE SUPPORT CLOSURE CHARACTERISTICS

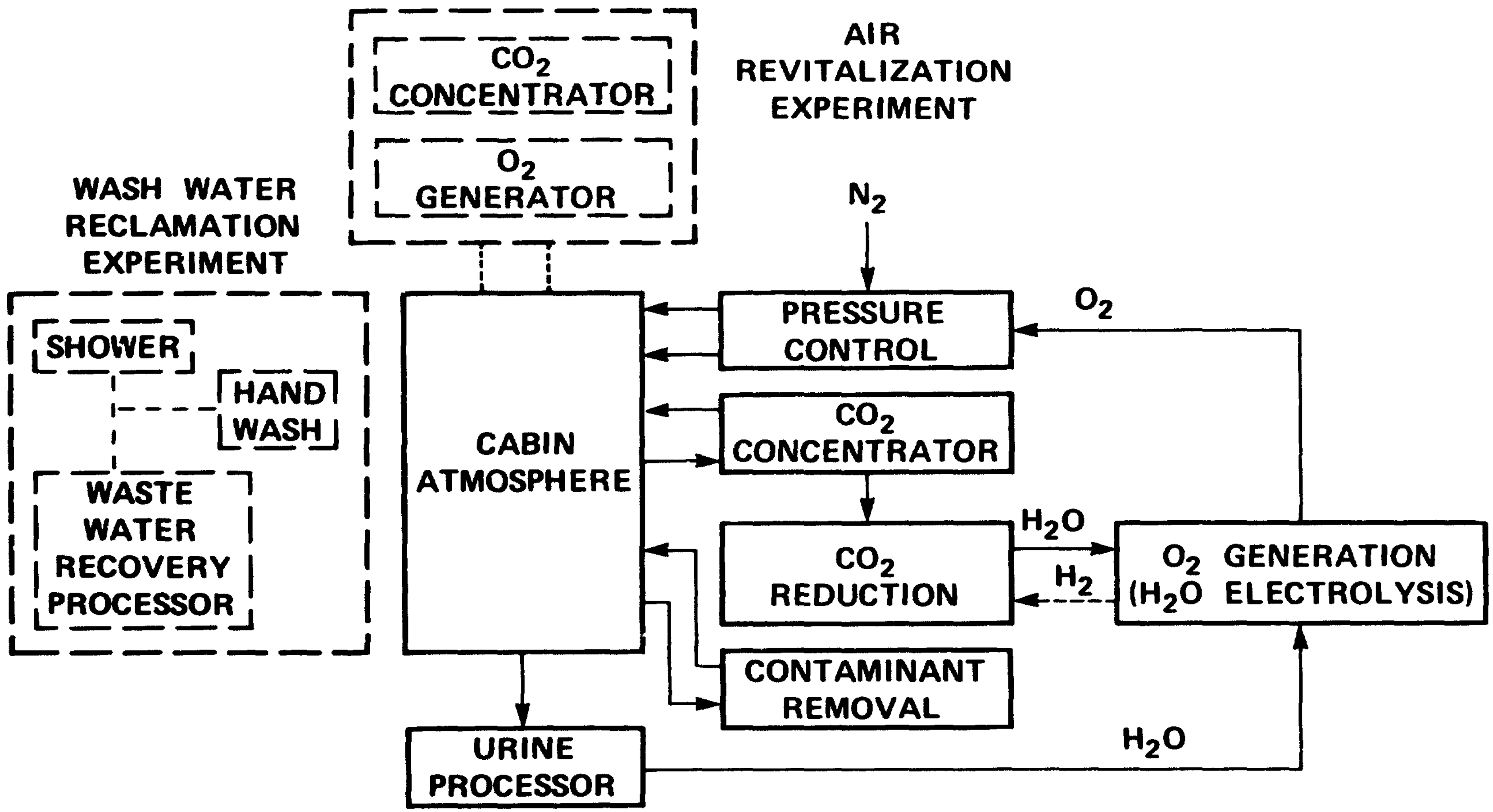


FORECASTED LIFE SUPPORT RESOURCE PROFILES



ITEM
1 REGEN EXP
2 SMALL STATION
3 LARGE STATION
4 LUNAR COLONY
5 SPACE BASE
6 LUNAR HABITAT
7 MARS LANDER
8 L5 HABITAT EXP.

REGENERATIVE ECLSS EXPERIMENT (SPACELAB)



LIFE SUPPORT EXPERIMENT CANDIDATES FOR SHUTTLE

1- REGENERABLE ENVIRONMENTAL CONTROL LIFE SUPPORT SYSTEM EXPERIMENT

2- SUBSYSTEM EXPERIMENTS*
   - A- WATER RECOVERY (VAPOR COMPRESSION DISTILLATION)
   - B- WATER ELECTROLYSIS (SOLID POLYMER ELECTROLYTE)
   - C- NITROGEN GENERATOR
   - D- CREW APPLIANCES
   - E- SOLID WASTE MANAGEMENT

   * AUTONOMOUS EXPERIMENTS OR INTEGRATED WITH ONE ABOVE

3- PRELIMINARY BIOLOGICAL SYSTEMS:
   MICROBIOLOGICAL/PLANT/ANIMAL EXPERIMENTS
   (PLANNED BY LIFE SCIENCES PAYLOAD PLANNING GROUP)

DEFINITION OF TECHNOLOGY REQUIREMENT NO. 1

1. TECHNOLOGY REQUIREMENT (TITLE): Demonstration of Regenerative-Class ECLSS Technology PAGE 1 OF 3

2. TECHNOLOGY CATEGORY: N-7-1

3. OBJECTIVE/ADVANCEMENT REQUIRED: Regenerative ECLSS technology demonstration is required to preclude excessive long term mission spacecraft penalties incurred by open-loop ECLSS.

4. CURRENT STATE OF ART: Basically, only non-regenerative (open-loop) systems have been demonstrated in zero gravity.

HAS BEEN CARRIED TO LEVEL 5

5. DESCRIPTION OF TECHNOLOGY

Current state-of-the-art systems utilize expendables to satisfy daily crew requirements resulting from metabolic processes such as oxygen consumption (2.6 lbs) water consumption (10 lbs.) and carbon dioxide generation (3.0 lbs). The weight to satisfy these particular requirements becomes prohibitive for long-term space flights as illustrated below for 6-man/6-month mission:

Current ECLSS (Shuttle-Type)	Regenerative ECLSS (Space Station Type)
8.4 Tons (Expendables Only)	3060 lbs. (Process Hardware plus Expendables)

P/L REQUIREMENTS BASED ON: ☐ PRE-A, ☒ A, ☐ B, ☐ C/D

6. RATIONALE AND ANALYSIS:

Most critical parameters for any ECLSS are man-days of the mission and resupply intervals for expendables. There are other key parameters that are man-related but not as critical: CO_2 partial pressure and crew water use allocations. Other parameters are vehicle-related such as type of electric power source (for example, fuel cells produce water, solar arrays don't and gas storage method (high pressure, cryogenic, none). All long-term manned missions, such as space station, lunar base, space power satellites, etc. benefit from regenerative-class ECLSS. Current state-of-the-art (open-loop) severely limit mission duration because of prohibitive H_2O and O_2 requirements.

Operate a demonstration model in space environment through various modes including steady state, transient, long-term, starts, stops. Additional ground-based tests to:

1. Uprate to final crew size
2. Improve reliability (by improving maint. designs)
3. Upgrade to keep pace with data management requirements
4. Incorporate advancements in weight, power volume

TO BE CARRIED TO LEVEL 7

DEFINITION OF TECHNOLOGY REQUIREMENT	NO. 1

1. TECHNOLOGY REQUIREMENT(TITLE): Demonstration of Regenerative-Class ECLSS Technology — PAGE 2 OF 3

7. TECHNOLOGY OPTIONS:

Continued use of oper ECLSS technology imposes enormous penalties for long duration flight. (Skylab, typical of open loop and long duration, carried 12000 lbs. of water for example). This technology is well understood but extremely large and heavy. Regenerative systems are next on the spectrum and are the object of the technology requirement. Further advancements are in early stages of development which offer improvements in closure of the system and in weight, power and volume penalties. These concepts are presently immature.

8. TECHNICAL PROBLEMS:

Optimum system integration of subsystems for high performance. Also, integration with the spacecraft. The basic technical design problem faced by the regenerative ECLSS is the ability to function efficiently in a zero gravity environment. (Liquid/vapor phase separation).

9. POTENTIAL ALTERNATIVES:

The regenerative ECLSS technology described is fundamental to long term manned mission unless massive spacecraft and boosters are developed, in which case, open loop ECLSS designs might suffice.

10. PLANNED PROGRAMS OR UNPERTURBED TECHNOLOGY ADVANCEMENT:

Engineering models being tested. Preprototype models being developed. Prototype and flight articles (duplicate of prototype) is the next step anticipated.

EXPECTED UNPERTURBED LEVEL 5

11. RELATED TECHNOLOGY REQUIREMENTS:

None defined.

DEFINITION OF TECHNOLOGY REQUIREMENT | NO.

1. TECHNOLOGY REQUIREMENT (TITLE): Demonstration of | PAGE 3 OF 3

12. TECHNOLOGY REQUIREMENTS SCHEDULE:

CALENDAR YEAR

SCHEDULE ITEM	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91		
TECHNOLOGY																			
1. **Engineering Breadboard Tests**																			
2. **Experiment definition and Preliminary design**																			
3. **Preprotype tests**																			
4.																			
5.																			
APPLICATION																			
1. **Design (Ph. C)**																			
2. **Devl/Fab (Ph. D)**																			
3. **Operations**																			
4.																			

13. USAGE SCHEDULE:

																		TOTAL
TECHNOLOGY NEED DATE									***									
NUMBER OF LAUNCHES									1									1

14. REFERENCES:

15. LEVEL OF STATE OF ART

1. BASIC PHENOMENA OBSERVED AND REPORTED.
2. THEORY FORMULATED TO DESCRIBE PHENOMENA.
3. THEORY TESTED BY PHYSICAL EXPERIMENT OR MATHEMATICAL MODEL.
4. PERTINENT FUNCTION OR CHARACTERISTIC DEMONSTRATED, E.G., MATERIAL, COMPONENT, ETC.
5. COMPONENT OR BREADBOARD TESTED IN RELEVANT ENVIRONMENT IN THE LABORATORY.
6. MODEL TESTED IN AIRCRAFT ENVIRONMENT.
7. MODEL TESTED IN SPACE ENVIRONMENT.
8. NEW CAPABILITY DERIVED FROM A MUCH LESSER OPERATIONAL MODEL.
9. RELIABILITY UPGRADING OF AN OPERATIONAL MODEL.
10. LIFETIME EXTENSION OF AN OPERATIONAL MODEL.

R E Q U I R E M E N T   F O R   B A S I C   R E S E A R C H

* CONCEPT
(MISSION/TECHNOLOGY/INSTRUMENT/SENSOR/SYSTEM) Water Quality Standards.

Water provision systems in present and future spacecraft furnish both hot and cold water for human consumption (drinking, food preparation) and for personal cleaning. Additional consideration of purity standards is needed to insure crew safety and wellbeing.

* WHAT CAN YOU TELL US QUANTITATIVELY ABOUT THIS PROBLEM?

At the present time only limited standards (provided by the National Academy of Sciences, etc) are available, setting forth allowable limits of chemical and biological contaminants. Additional consideration of maximum allowable concentration of contaminants and for other constraints (e.g., turbidity, ph. etc) is needed to establish additional guidance and testing of such water provision systems and the associated biocidal treatment of the processed water.

* BASIC RESEARCH REQUIRED:

Identify purity standards, methodology and measurement technique for establishing "safe" water.

* WORKING GROUP MEMBER TO BE CONTACTED FOR FURTHER DISCUSSION :

D.C. Popma, NASA Hg. Code MMV
R.J. Gillen, NASA J.S.C. EC-3 (non working group member)

REQUIREMENT FOR BASIC RESEARCH

* CONCEPT:
(MISSION/TECHNOLOGY/INSTRUMENT/SENSOR/SYSTEM)

Improved air quality standards must be established for contaminant control.

* WHAT CAN YOU TELL US QUANTITATIVELY ABOUT THIS PROBLEM?

In past, manned spacecraft have had a relatively clean cabin environment due to control of cabin structural materials. With the advent of A14.78SIA cabin pressure, mat'ls control will be relaxed and new potential contaminants may result. So more comprehensive std's are red'd. for design and performance testing of contaminant control systems.

* BASIC RESEARCH REQUIRED:

Identify Manned Spacecraft Air Quality Standards

* WORKING GROUP MEMBER TO BE CONTACTED FOR FURTHER DISCUSSION:

NASA AMES MAIL CODE 239-4		415-965-5733	
Dr. W. Rippstein	NASA JSC		
R.J. Gillen	NASA JSC EC3	713-483-5536	Not working group members

REQUIREMENT FOR BASIC RESEARCH

* CONCEPT:
  (MISSION/TECHNOLOGY/INSTRUMENT/SENSOR/SYSTEM) EXTRAVEHICULAR CONTAMINATION RESTRICTIONS AND IMPACT ON OPTICAL SENSORS.

Spacecraft leakage, EMU leakage and EMU thermal control (water vapor) as well as spacecraft ECS venting will allow contaminants to be released in the vicinity of the shuttle, with potential detrimental effect on optical sensor systems. There is a need to quantify these detrimental effects (if any) to preclude data loss or error, and at the same time, not restrict EVA operations, and other spacecraft operations unduly.

* WHAT CAN YOU TELL US QUANTITATIVELY ABOUT THIS PROBLEM?

Consideration should be given to the following:

- -sensor protection or configuration changes
- -modification of vent locations or time sequencing
- -decay rates of contaminants with time
- -potential for contamination by various vapors and gases (e.g., water, CO, etc.)
- -synergistic effects of mixed contaminants

* BASIC RESEARCH REQUIRED:

TBD.

* WORKING GROUP MEMBER TO BE CONTACTED FOR FURTHER DISCUSSION:

D.C. Popma,	NASA Hg.	Code MMV
P.D. Quattrone	NASA	ARC.

REQUIREMENT FOR BASIC RESEARCH

* CONCEPT:
(MISSION/TECHNOLOGY/INSTRUMENT/SENSOR/SYSTEM)

There is a need, for duration manned missions, to perform whole body bathing and clothes laundering. The degree of cleanliness required in this circumstance is not known, but will impact the design of equipment required to perform the cleansing functions. In addition, water usage must be as low as possible and soaps must be compatible with cleanliness requirements as well as the personel hygiene equipment, water processors, and the crewmen.

* WHAT CAN YOU TELL US QUANTITATIVELY ABOUT THIS PROBLEM?

Virtually no attempt has been made to qualify acceptable personal cleanliness in terms of comfort or lack of micro flora on the skin. Prototype washer/dryers, designed on the basis of using soap and water as the cleaning agents, have a 25 to 1 ratio of required water weight to clothing load. Available soap formulation considered acceptable for personal hygiene is space have been tested with reverse osmosis water processors; evoked in skin patch tests and a soap, miranol, was used in Skylab but was not liked in terms of odor and comfort. No currently available soap or cleansing agent is completely acceptable.

* BASIC RESEARCH REQUIRED:

Identify cleanliness requirements for long duration space mission crewmen. Identify technology advancements necessary to improve weight, volume and power penalties of washer/dryer concepts that have been previously suggested because of their potential utility. Formulate a soap that is completely compatible with man, water processors and personal hygiene equipment.

* WORKING GROUP MEMBER TO BE CONTACTED FOR FURTHER DISCUSSION:

O.K. Houck, NASA JSC EC2 713-483-4336

R.J. Gillen, NASA JSC EC3 713-483-5536